UNCLASSIFIED

~~CONFIDENTIAL~~

COPY NO. 6

RM No. E8A28a

NACA CLASSIFICATION CHANGED TO RESTRICTED

~~RESTRICTED~~

14 JUL 1948

c.1

NACA

RESEARCH MEMORANDUM

BENCH AND ENGINE OPERATION OF A FUEL-DISTRIBUTION CONTROL

By Harold Gold and Robert J. Koenig

Flight Propulsion Research Laboratory
Cleveland, Ohio

CLASSIFICATION CANCELLED

Authority J. W. Crowley Date 12/14/53
EO 10501

By JH 1-12-54 See NACA
RF1968

CLASSIFIED DOCUMENT

This document contains classified information affecting the National Defense of the United States within the meaning of the Espionage Act, USC 50:31 and 32. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law. Information so classified may be imparted only to persons in the military and naval services of the United States, appropriate civilian officers and employees of the Federal Government who have a legitimate interest therein, and to United States citizens of known loyalty and discretion who of necessity must be informed thereof.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
June 14, 1948

~~CONFIDENTIAL~~

UNCLASSIFIED

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

BENCH AND ENGINE OPERATION OF A FUEL-DISTRIBUTION CONTROL

By Harold Gold and Robert J. Koenig

SUMMARY

The study of the application of a fuel-distribution-control method to actual gas-turbine-engine operation is described. The control used was designed to equalize the flow to each of the 14 nozzles of a gas-turbine engine. A mathematical analysis of possible control ranges with this method of fuel-distribution control is presented in the appendix. The performance of the control on the bench and on the engine was very nearly identical. The maximum measured deviation from perfect distribution during engine operation, considering the richest or leanest of the 14 lines, was 3.8 percent. It was shown that the control model is capable of maintaining this accuracy independently of changes in fuel-nozzle resistance from 0 up to 1.46 times the resistance of a normal engine fuel nozzle.

INTRODUCTION

An investigation of methods of obtaining improved fuel atomization and distribution in gas-turbine engines is being made at the NACA Cleveland laboratory. In the course of this investigation, a control system was developed (reference 1) that provides a means of consistently obtaining uniform fuel distribution.

In order to determine the ability of the system to function under engine operating conditions, a control was built for a gas-turbine engine having 14 fuel nozzles. The objects of this investigation were to determine: (a) the limits of control range, and (b) the uniformity of distribution that could consistently be obtained during bench and engine operation of this control. The control was used in the operation of the gas-turbine engine through several sea-level static runs during which the fuel flow delivered to each nozzle was measured. A description of the control and the results of bench and engine runs are presented. A mathematical analysis of possible control ranges with this method of fuel-distribution control is presented in the appendix.

APPARATUS

Fuel-distribution-control model. - A cross section of the fuel-distribution control used in this investigation is presented in figure 1. The control comprises 14 control elements plus a pilot element. A control element consists of a branch metering jet, a downstream pressure-regulating valve, a control diaphragm, and pressure chambers. Fuel is delivered under pressure to the low-resistance manifold passage from which it flows through the branch metering jets. From each branch metering jet, the fuel flows into a pressure chamber B, through a downstream pressure-regulating valve, and out to an engine fuel nozzle. Fuel also flows through the pilot metering jet, through the pilot regulator jet, and through the pre-set pilot resistance valve from which it returns to the tank. Each pressure chamber A is so vented to the pressure-equalizing passage that the loading pressure from the pilot system is equally transmitted to all control diaphragms. Each downstream pressure-regulating valve thereby regulates the chamber B pressure so that it is equal to the pilot loading pressure. The upstream pressure to all branch metering jets is maintained equal by the low-resistance manifold passage. These two functions combine to maintain equal pressure drop across all branch metering jets. With matched metering jets, the flows through all branches are therefore maintained equal. A more detailed discussion of the action of the control is given in reference 1.

The branch metering jets and pilot metering jet are 0.104 inch in diameter and the pilot regulator jet is 0.055 inch in diameter. The diametral clearance between the plunger and the guide of the downstream pressure-regulating valve is between 0.0002 and 0.0006 inch. A long-taper needle valve is used as the pilot resistance valve. The assembled control is shown in figure 2 and disassembled control element, in figure 3.

Engine fuel-discharge nozzles. - The fuel-discharge nozzles used in the bench and engine runs were of the vortex type currently used on the engine. Each of these nozzles has a nominal rating of 40 gallons per hour at 100 pounds per square inch pressure drop. The metering pins normally used with these nozzles were removed from the nozzle assembly because they are unnecessary when the distribution control is used and because the removal reduced the maximum required supply pressure.

Bench apparatus. - The bench apparatus used for checking the operation of the fuel-distribution control is schematically shown in figure 4. The fuel flow to each of the 14 nozzles was measured with a pair of rotameters. Each pair consisted of a rotameter having a range of 15 to 150 pounds per hour connected in series with one having a range of 100 to 500 pounds per hour. The needle valve shown in figure 4 was used to simulate varying nozzle or line resistance. The needle valve could be substituted for any one of the 14 nozzles. The pressure to the control and the pressure upstream of the needle valve were measured with pressure gages, each having a range from 0 to 500 pounds per square inch. The bench and engine fuel used was kerosene. A photograph of the bench installation is shown in figure 5.

Engine installation. - For the engine runs, the fuel-distribution control was mounted on a gas-turbine engine having 14 fuel nozzles. As shown in the schematic diagram of figure 6, the control replaced the conventional fuel manifold in the engine fuel system. The fuel flowed through the engine throttle to the control. The control distributed the flow to 14 separate lines, each of which was connected to an engine fuel-discharge nozzle through a rotameter having a range of 100 to 500 pounds per hour. The same rotameters, in the same relative positions, were used for both bench and engine studies. In order to place the rotameters in a reasonably quiet and vibration-free location, it was necessary to use in each branch approximately 100 feet of tubing to conduct the fuel from the control to the rotameters and back to the engine. The 1/4-inch tubing used caused an average pressure drop through the tubing and fittings of 175 pounds per square inch at a line flow of 320 pounds per hour; the variation from the average pressure drop among the lines was approximately 50 pounds per square inch. The arrangement is shown in the sketch of figure 7. The control mounted on the engine is shown in figure 8.

PROCEDURE

Pilot-resistance-valve settings. - During the bench runs, the pilot resistance valve and the engine fuel nozzles discharged to the same pressure (atmospheric). The pilot resistance valve was adjusted in these runs to have a resistance approximately equal to the nominal rating of the engine fuel nozzles. During the engine runs, the pilot resistance valve discharged against atmospheric pressure whereas the engine fuel nozzle discharged against combustion-chamber pressure. In order to compensate for this difference, the pilot resistance valve was adjusted to a greater resistance during the engine runs than during the bench runs.

Bench operation. - The bench runs were divided into two parts. The first part consisted of a check of the individual control elements to determine the ranges of compensation for variation in nozzle or nozzle-line resistance. This check was made by connecting a needle valve to the outlet of one control element at a time, as described in the section entitled "Bench apparatus." The fuel pressure to the control was kept constant and the open area of the needle valve was varied. At each increment of the needle-valve opening, the readings of the rotameter and of the pressure gage in that line were recorded.

The second part of the bench runs consisted in checking the performance of the entire fuel-distribution control. The over-all performance was checked by setting up a condition of unequal nozzle resistance. The control was connected to a set of unmatched fuel nozzles, which were selected to give a difference in flow among the nozzles of ± 10 percent when connected to a common manifold (equal pressure drops across the nozzles). The total fuel flow to the fuel-distribution control was set at several values between 470 and 4500 pounds per hour. At each flow setting, the 14 rotameter readings were recorded.

Engine operation. - The engine speed was set at several values between 70 percent of maximum speed and maximum speed. At each speed setting, the 14 rotameter readings were recorded.

RESULTS AND DISCUSSION

Pilot-resistance-valve settings. - The use of different pilot-resistance-valve settings during bench and engine runs was a laboratory expedient rather than a practical solution of the problems involved. Two methods have been considered that permit a single pilot-resistance-valve setting to satisfy all conditions of engine operation. In the first method, the pilot system replaces one of the control elements and an engine fuel nozzle is used as the pilot nozzle. This method was not employed because of the extremely long fuel lines required in this engine setup, in which the variation in line resistance would have made the pilot resistance uncertain. In the second method, the pilot resistance valve discharges through a pressure-regulating valve vented to a combustion-chamber from which the fuel returns to the tank. The simple expedient of adjusting the pilot nozzle to a higher resistance was a satisfactory approximation to the second method for sea-level static engine operation.

Instrument accuracy. - It was a primary object of this investigation to determine the accuracy that could be consistently achieved with the fuel-distribution control; therefore, the accuracy of flow measurement was an important consideration. A simultaneous calibration was made of the fourteen 100- to 500-pound-per-hour rotameters by connecting them in series; the process was repeated with the 15- to 150-pound-per-hour rotameters. Continuous readings at constant flows showed that the 100- to 500-pound-per-hour rotameters were subject to changes in readings of ±5 pounds per hour among rotameters over the entire range and that the 15- to 150-pound-per-hour rotameters were subject to changes in readings of ±1.5 pounds per hour. In addition to these normal variations, the rotameters were subject to change in calibration due to variations in the friction between float and guide. Continual checking of 28 rotameters would have consumed an excessive amount of time; therefore, rotameter calibrations were checked only when float-sticking occurred.

All data shown are observed rotameter values and therefore include these possible errors. Because of the random nature of these errors, it would have been possible to select one run out of several in which the fuel-distribution-control error appeared to be smaller or larger than shown in the figures. The data shown in the figures for the bench runs are representative of the accuracy that was consistently attained, using a precalibrated set of rotameters in which the floats were known to be free.

Bench runs. - The range of controllable nozzle calibrations as determined from the bench runs is shown in figure 9. The data points shown are the flows and pressures recorded as described in the section entitled "Bench operation". The pressures given at each datum point of runs 1, 2, and 3 are the pressures to the needle valve that were automatically adjusted by the control in order to maintain the constant flow through the needle valve at its various settings. At a pressure of zero gage in figure 9, the needle valve was at its maximum opening and was equivalent to an open line. It can be noted that up to the point at which the flow rapidly diminishes, which is the pressure at which the downstream pressure-regulating valve within the control element reaches its maximum opening, the flow is for all practical purposes independent of nozzle resistance. The solid curve drawn through these maximum-pressure points represents the calibration curve of the fuel nozzle with the highest resistance that can be controlled by the distribution-control model used in this investigation. Any set of nozzles whose calibration curves fall within the shaded area in figure 9 would give uniform fuel distribution when used with this control model. A mathematical analysis of this control range is given in the appendix. The dashed curve shown in figure 9 is the calibration curve of the pilot resistance valve and is equal to the nominal rating of the engine fuel nozzles. At all flows, the pressure of the solid curve is 1.46 times the dashed curve.

904

The performance on the bench of the fuel-distribution control where the flow to 14 unmatched nozzles is controlled is shown in figure 10. In the range of nozzle flow between 119 and 340 pounds per hour, the maximum measured deviation of any one line from perfect distribution was 2.8 percent. In the range of nozzle flow between 33 and 119 pounds per hour, the maximum measured deviation from perfect distribution was 7.5 percent, but it should be noted that this is the result of a deviation of only 2 pounds per hour with a possible rotameter error of 1.5 pounds.

Engine runs. - The performance on the engine of the fuel-distribution control is shown in figure 11. In all the engine runs, the maximum measured deviation in any one line from uniform distribution was no greater than 3.8 percent. The flow range during engine runs was 132 to 319 pounds per hour. Because the lower range rotameters were unavailable at the engine stand, data could not be obtained below 100 pounds per hour. 904

Comparison of bench and engine runs. - A comparison between the bench and engine runs shows a marked similarity in control performance not only in the numerical values of the deviations but also in the over-all distribution patterns. In considering this similarity, several factors should be kept in mind: (1) A great difference in line- and nozzle-resistance patterns existed between the two runs; (2) in the engine runs, the control was subject to engine vibration whereas no vibration was present on the bench; and (3) the same 14 rotameters that were used on the bench were used in the engine runs in the same relative positions, with the fuel-flow values being obtained from the same calibration curves.

The first factor indicates that the control-element performance shown in figure 9, which indicated that flow from a control element was independent of the nozzle or line resistance, applies to the performance of the fuel-distribution control as a whole. The second factor indicates that accuracy of the control is unaffected by engine vibration. The third factor indicates that there may have been an error in the rotameter-calibration curves other than the random error and that the actual distribution may therefore have been more uniform than that shown in figures 10 and 11. The maximum deviation obtained in both bench and engine operation are tabulated as follows along with the possible random rotameter error:

Mean branch flow (lb/hr)	Bench run		Engine run	
	Maximum observed deviation (percent)	Possible random rotameter error (percent)	Maximum observed deviation (percent)	Possible random rotameter error (percent)
33	7.5	4.6	---------	---------------
67	6.6	2.2	---------	---------------
119	1.7	1.3	---------	---------------
133	---------	---------------	1.5	3.8
163	---------	---------------	2.3	3.1
183	2.4	2.7	---------	---------------
209	---------	---------------	2.3	2.4
236	2.8	2.1	---------	---------------
274	---------	---------------	2.4	1.8
297	2.5	1.7	---------	---------------
319	---------	---------------	3.8	1.6
340	2.5	1.5	---------	---------------

SUMMARY OF RESULTS

From bench and engine runs of a fuel-distribution control designed for operation on a gas-turbine engine having 14 fuel nozzles, the following results were obtained:

1. The performance of the control model on the bench and on the engine was very nearly identical. The maximum measured deviation from uniform distribution during engine operation, considering the richest and leanest of the 14 lines, was 3.8 percent.

2. The control model was found to be capable of maintaining fuel distribution uniform within 3.8 percent with any set of nozzles whose resistances vary from 0 up to 1.46 times the nominal resistance of the engine fuel nozzle.

Flight Propulsion Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

APPENDIX - ANALYSIS OF CONTROL RANGE

General Analysis

The purpose of this analysis is to show the relation between the various control elements and the control operating range. The fuel-distribution control will function over a range of engine fuel-nozzle resistances both larger and smaller than the nominal engine fuel-nozzle resistance. In this analysis, the lower limit of control range is taken as that corresponding to an open fuel line or zero resistance. The flow through the pilot element is taken as being equal to the flow through the control element and it is assumed that provisions are made for the pilot nozzle to discharge against combustion-chamber pressure. Throughout the analysis, the combustion-chamber pressure is the reference zero gage pressure.

The following symbol notations (see fig. 1) are used in the analysis:

A area, sq in.

C coefficient of discharge

g acceleration due to gravity, 32.2 ft/sec^2

n unit conversion factor, $\frac{3600}{12} = 300$ (sec/hr) (ft/in.)

P_1 manifold passage pressure, lb/sq in. gage

P_2 pressure of chamber A and B, lb/sq in. gage

P_3 pilot resistance-valve pressure, lb/sq in. gage

P_4 engine fuel-nozzle pressure, lb/sq in. gage

ΔP pressure drop, lb/sq in.

W branch flow, lb/hr

ρ density of fuel, lb/cu ft

Subscripts:

b branch metering jet

c fuel-distribution control

e engine fuel nozzle

m pilot metering jet

p pilot resistance valve

r pilot regulator jet

v downstream pressure-regulating valve

max maximum

min minimum

The following constants are used to simplify the flow equation:

J dimensional constant, $nC\sqrt{2g\rho}\ \frac{lb^{1/2}}{(in.)(hr)}$

K constant in equation defining a simple parabolic flow-pressure relation $(\Delta P = KW^2)$, $\frac{1}{nAC\sqrt{2g\rho}}$, $\frac{hr^2}{(in.^2)(lb)}$

N control range, $\frac{K_e}{K_p}$

<u>Control operation.</u> - Under any operating conditions, the pressure relations in each control element and in the pilot element may be expressed by the following equation:

$$\Delta P_b + \Delta P_v + \Delta P_e = \Delta P_m + \Delta P_r + \Delta P_p \tag{1}$$

The control functions to maintain ΔP_b in each control element equal to ΔP_m in the pilot element; therefore, when the control is within the useful range of operation, each control element is operating so that

$$\Delta P_v + \Delta P_e = \Delta P_r + \Delta P_p \tag{2}$$

The control acts by varying ΔP_v (accomplished by varying A_v) to compensate for differences in ΔP_e (caused by variations in the resistances of the various engine fuel nozzles).

If equal flows are to be maintained to the various engine fuel nozzles, then the branch metering jet must be matched so that $A_b C_b$ is equal in each control element. The flow through the pilot element can be in any fixed ratio to the flow to the engine fuel nozzles by adjusting $A_m C_m$. It is advantageous, however, to make the flow through the pilot element equal to the flow through the engine fuel nozzles by making $A_m C_m = A_b C_b$. This procedure avoids extremely small jets in the pilot element, as could be the case if the pilot flow were reduced, and simplifies the matching of the control-element components to the pilot-element components.

Relation between control range and range of open area of downstream pressure-regulating valve. - The open area of the downstream pressure-regulating valve is expressed by the following equation:

$$A_v = \frac{W}{J\sqrt{P_2 - P_4}} \tag{3}$$

The pilot system controls P_2 so that

$$P_2 = P_3 + \Delta P_r$$

By assuming a simple parabolic flow-pressure relation,

$$P_3 = \Delta P_p = K_p W^2$$

$$P_4 = \Delta P_e = K_e W^2$$

$$\Delta P_r = K_r W^2$$

By substitution in equation (3),

$$A_v = \frac{W}{J\sqrt{K_p W^2 + K_r W^2 - K_e W^2}}$$

Simplifying,

904

$$A_v = \frac{1}{J\sqrt{K_p + K_r - K_e}} \tag{4}$$

It can be seen from equation (4) that A_v is independent of the flow. As long as the engine-nozzle resistance K_e remains constant, the valve area A_v remains constant. When K_e varies, A_v must vary. If K_p and K_r remain constant, the range of values of K_e that can be compensated for by the control is determined by the range of A_v.

The limiting values of K_e can be expressed as a multiple of the constant K_p in which

$$\frac{K_{e,max}}{K_p} = N_{max} \tag{5}$$

and

$$\frac{K_{e,min}}{K_p} = N_{min} \tag{5a}$$

By substituting equations (5) and (5a) in equation (4), N_{max} and N_{min} can be evaluated in terms of K_p, K_r, and A_v. From which,

$$N_{max} = \frac{K_p + K_r - \left(\frac{1}{J\ A_{v,max}}\right)^2}{K_p} \tag{6}$$

and

$$N_{min} = \frac{K_p + K_r - \left(\frac{1}{J\ A_{v,min}}\right)^2}{K_p} \qquad (6a)$$

The values of N_{max} and N_{min} can be used to determine the range of engine fuel-nozzle pressures P_4 that can be set by the control in order to maintain equal flows. 904

$$\frac{P_{4,max}}{P_3} = \frac{K_{e,max}}{K_p}$$

and

$$\frac{P_{4,min}}{P_3} = \frac{K_{e,min}}{K_p}$$

from which

$$P_{4,max} = N_{max}\ P_3 \qquad (7)$$

and

$$P_{4,min} = N_{min}\ P_3 \qquad (7a)$$

If it is desired to extend the range of the control to zero engine-fuel-nozzle resistance, then

$$P_{4,min} = 0$$

and

$$N_{min} = 0$$

By substituting $N_{min} = 0$ into equation (6a),

$$A_{v,min} = \frac{1}{J\sqrt{K_p + K_r}} \tag{8}$$

904 This area is the required valve area at the lower limit of the control range, which occurs at zero engine-nozzle resistance.

At a given flow, the upper limit of the control range $P_{4,max}$ may be increased by increasing P_3 or N_{max} (equation (7)). By increasing $A_{v,max}$ (equation (6)), N_{max} may be increased but in this case, N_{max} will increase only up to a maximum value of

$$N_{max} = \frac{K_p + K_r}{K_p}$$

where $A_v = \infty$. Therefore, when K_p and K_r are set, there is a practical limit to the maximum area of the downstream pressure-regulating valve.

The upper limit of the control range $P_{4,max}$ may be increased by increasing K_p and K_r, but for a given value of $A_{v,min}$, increasing K_p and K_r will raise the lower limit $P_{4,min}$.

<u>Distribution-control pressure drop.</u> - The inlet pressure required by the control will be the sum of the pressure drops through the pilot system and is expressed in the following equation:

$$P_1 = \Delta P_m + \Delta P_r + \Delta P_p \tag{9}$$

assuming the simple parabolic pressure-flow relation,

$$\Delta P_m = K_m W^2$$

$$P_1 = K_m W^2 + K_r W^2 + K_p W^2$$

$$P_1 = W^2 (K_m + K_r + K_p) \tag{10}$$

The pressure drop across the control is defined as the difference between the inlet pressure and the nominal engine-fuel-nozzle pressure and is therefore

$$\Delta P_c = W^2 \ (K_m + K_r + K_p) - W^2 K_e \ (\text{nominal})$$

$$\Delta P_c = W^2 \ (K_m + K_r + K_p - K_e \ (\text{nominal})) \qquad (11)$$

904

In the case where the pilot resistance valve is adjusted to the resistance equal to the nominal rating of the engine fuel nozzles,

$$K_p = K_e \ (\text{nominal})$$

and

$$\Delta P_c = W^2 \ (K_m + K_r) \qquad (11a)$$

It can be seen from equation (11a) that the maximum values of K_m and K_r (limits of minimum area of branch metering jet A_m or A_b and pilot regulator jet A_r may be finally determined by the maximum allowable pressure drop across the distribution control. The minimum practical jet area from a standpoint of cavitation is a further consideration. Very small jets are also subject to clogging.

<u>Branch-metering-jet size.</u> - There is no fixed relation between the size of the branch metering jet and the size of the other components. The size is selected on the basis of range of fuel flow. In the first place, the jet must be large enough to avoid cavitation at the maximum flow. Secondly, the jet must be small enough to produce a pressure drop at the minimum flow large enough to be controlled accurately by the downstream pressure-regulating valve.

Application of Analysis to Control Used in this Investigation

<u>Dimensions of downstream pressure-regulating valve.</u> - The pressures and pressure drops in the fuel-distribution control used in this investigation,as determined from bench runs, are shown in figure 12 from which

$$K_r = 0.00075 \frac{hr^2}{(in.^2)(lb)}$$

$$K_p = K_3 = 0.00155 \frac{hr^2}{(in.^2)(lb)}$$

$$K_b = 0.000059 \frac{hr^2}{(in.^2)(lb)}$$

The basic equation of flow of kerosene through the downstream pressure-regulating valve is

$$W = 17{,}000\ C_v A_v \sqrt{P_2 - P_4}$$

where $\rho = 49.9$ lb/cu ft.

From data obtained on the valve that was used in the investigation control model,

$$C_v = 0.59$$

Then

$$J = 17{,}000 \times 0.59 = 10{,}000 \frac{lb^{1/2}}{(in.)(hr)}$$

From the dimensions of the valve,

$$A_{v,max} = 0.017 \text{ sq in.}$$

From equation (6),

$$N_{max} = \frac{0.00155 + 0.00075 \left(\frac{1}{0.017^2 \times 10^8}\right)}{0.00155}$$

$$N_{max} = 1.46$$ [redacted]

It can be seen in figure 9 that the value of N_{max} closely matches the actual performance of the control.

If $A_{v,max}$ were equal to infinity, then from equation (7b)

$$N_{max} = \frac{0.00155 + 0.00075}{0.00155} = 1.48$$

from which it can be seen that little would have been gained from use of a larger valve.

The minimum required valve area from equation (8) is

$$A_{v,min} = \frac{1}{10{,}000 \sqrt{0.00155 + 0.00075}} = 0.00208 \text{ sq in.}$$

The minimum valve area with the valve construction used (fig. 1) is determined by the clearance between the valve plunger and the guide. There are two leakage paths, one on the top of the plunger and one on the bottom. The maximum allowable clearance area between plunger and guide is then 0.00104 square inch. The plunger diameter is 0.25 inch. The maximum allowable diametral clearance is then 0.00264 inch. The maximum diametral clearance used, which was 0.0006 inch, therefore satisfied the condition for minimum area.

It can be seen in figure 9 that this selection is justified by the results of the bench runs.

Branch-metering-jet size. - At the lowest branch flow investigated (33 lb/hr), the pressure drop across the branch metering jet was 2.2 inches of kerosene. It is apparent from the results, as shown in figures 9 and 10, that this pressure drop is large enough to be controlled accurately by the downstream pressure-regulating valve.

Distribution-control pressure drop. - From equation (11a), the pressure drop across the distribution control is

$$\Delta P_c = W^2 \ (0.000059 + 0.00075)$$

$$\Delta P_c = 0.000809 \ W^2$$

The maximum flow for the gas-turbine engine used was 320 pounds per hour per nozzle. The pressure drop across the control at maximum flow is then

$$\Delta P_c = 0.000809 \times 320^2$$

$$\Delta P_c = 83 \text{ lb/sq in.}$$

REFERENCE

1. Gold, Harold, and Straight, David M.: A Fuel-Distribution Control for Gas-Turbine Engines. NACA RM No. E8C08, 1948.

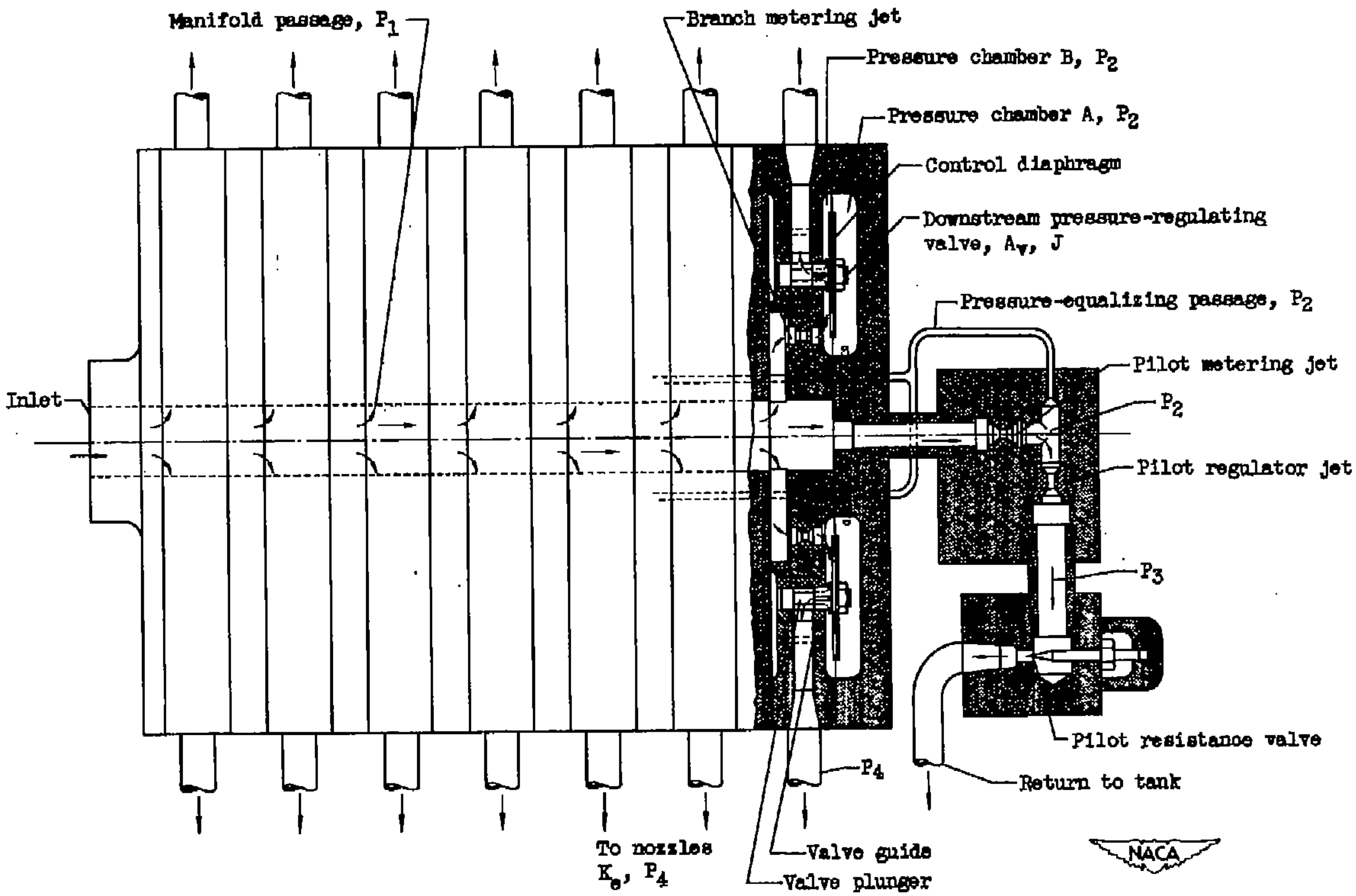
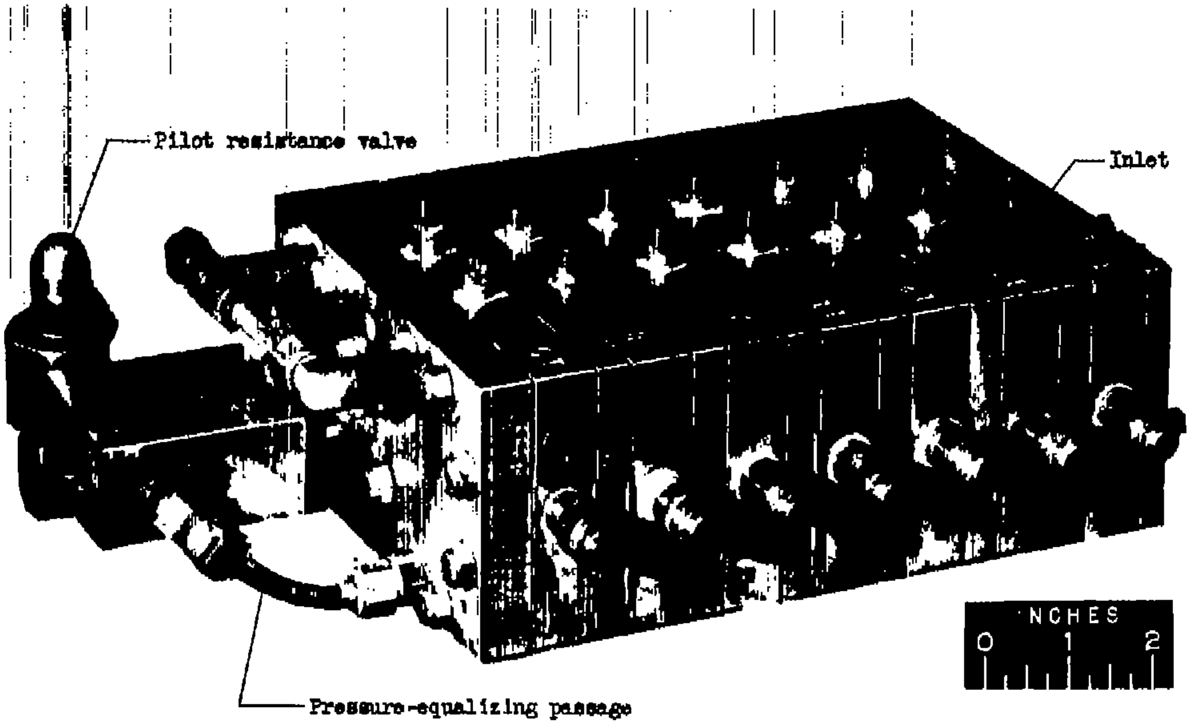


Figure 1. - Cross-sectional view of fuel-distribution control for gas-turbine engine having 14 nozzles.



NACA
C-18803
5-21-47

Figure 2. - Fuel-distribution control for gas-turbine engine having 14 fuel nozzles.

[redacted]

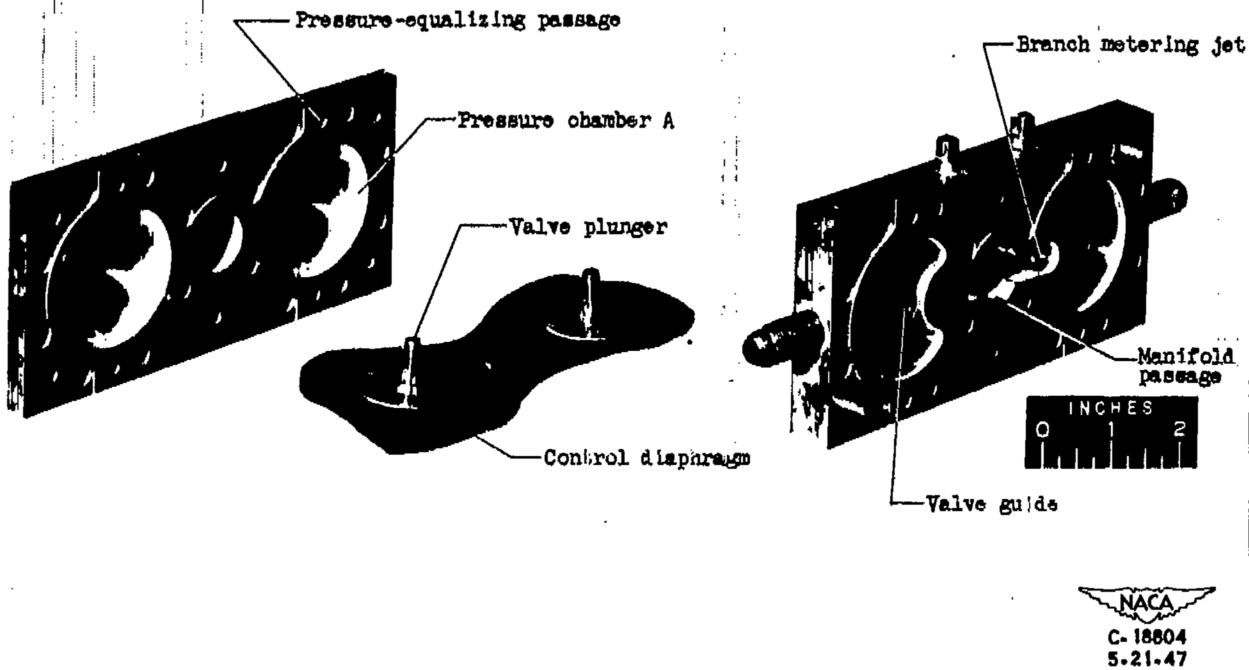


Figure 3. - Disassembled control element of fuel-distribution control for gas-turbine engine having 14 fuel nozzles.

[redacted]

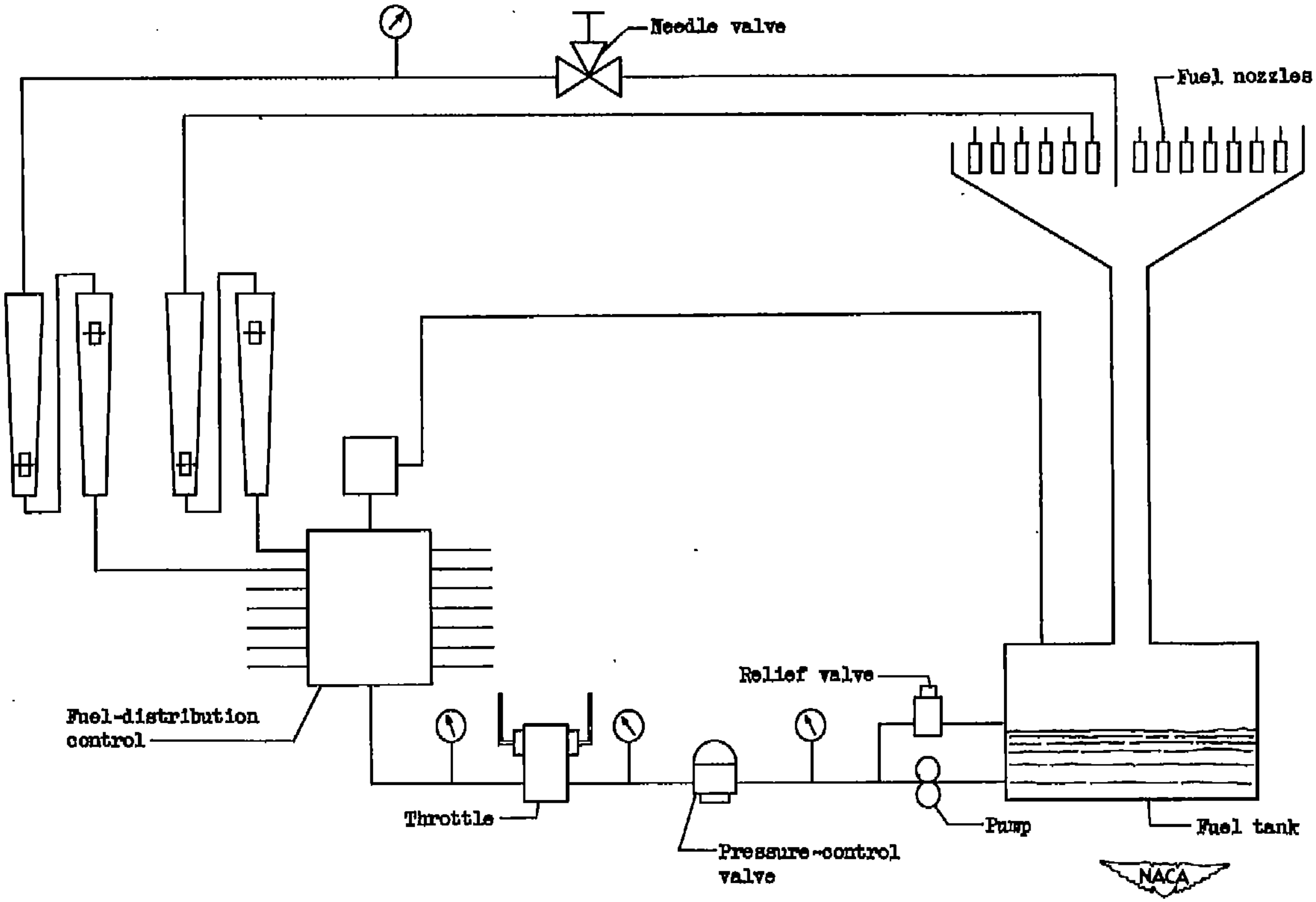
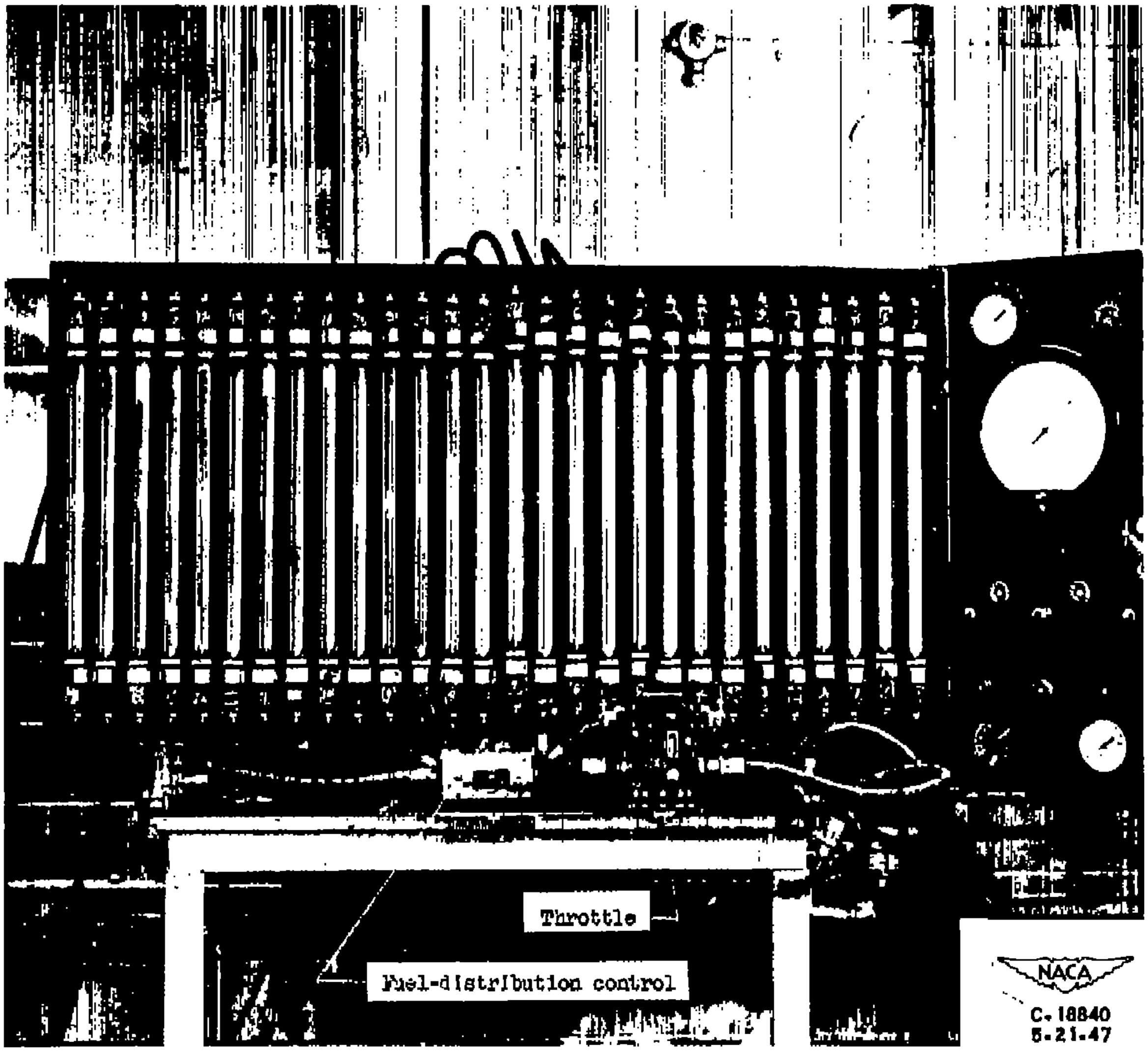


Figure 4. - Schematic diagram of bench apparatus used in fuel-distribution-control studies.



NACA
C-18840
5-21-47

Figure 5. - Bench apparatus used in fuel-distribution-control studies.

[redacted]

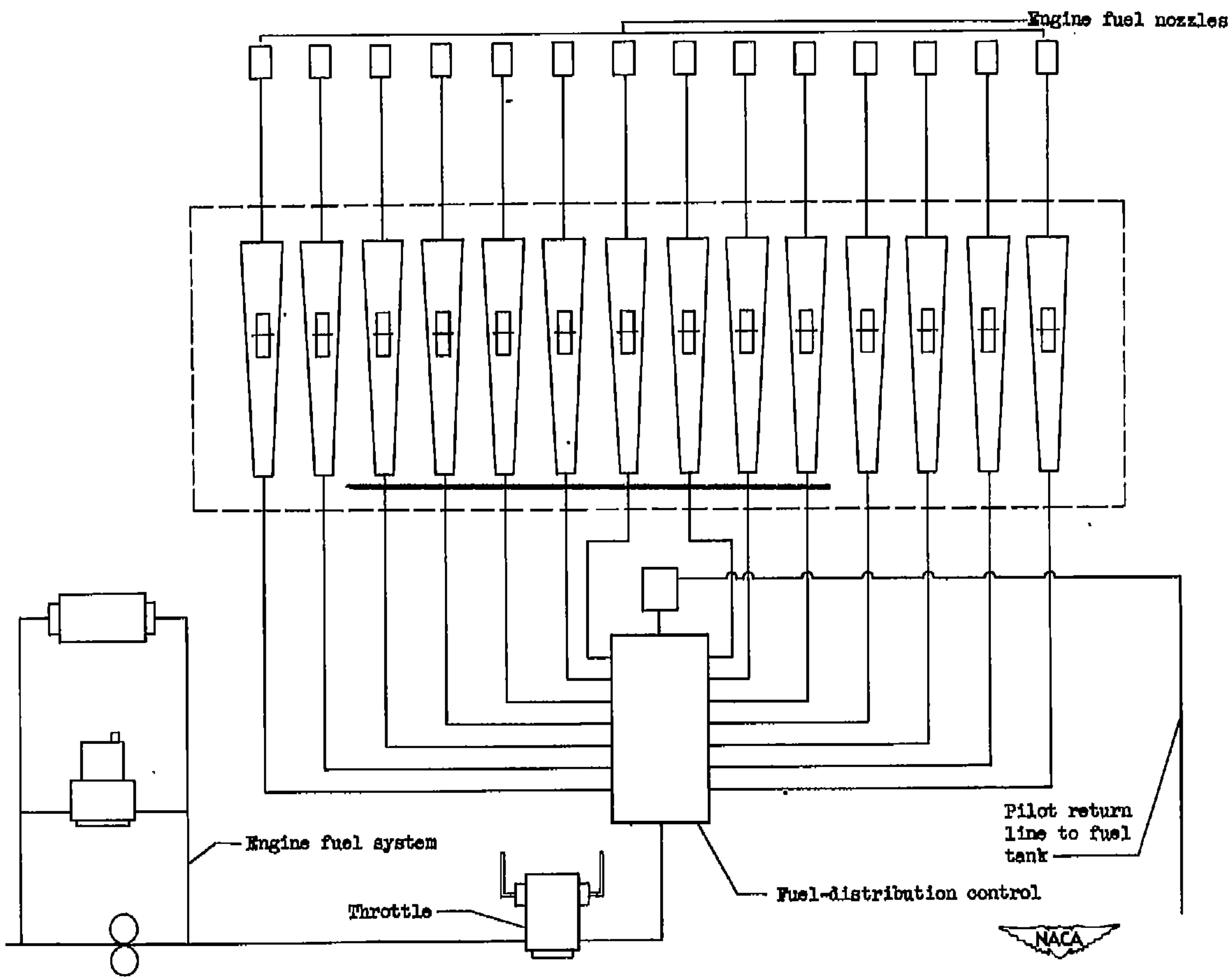


Figure 6. - Schematic diagram showing fuel-distribution control and rotameters in gas-turbine-engine fuel system.

[redacted]

[redacted]

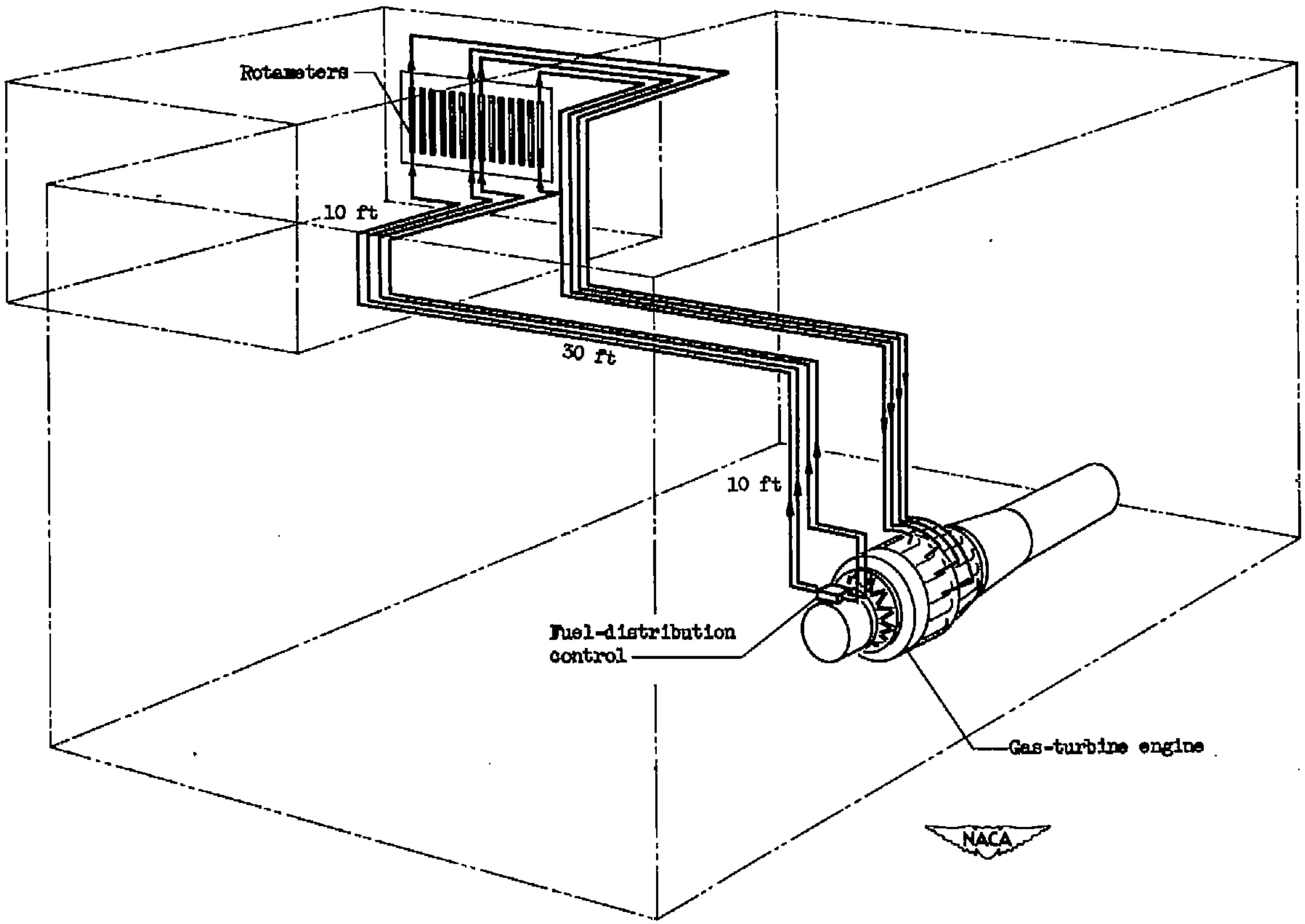


Figure 7. - Sketch showing layout of connecting tubing used in engine runs of fuel-distribution control.

[redacted]

904

Figure 8. - Fuel-distribution control installed on gas-turbine engine.

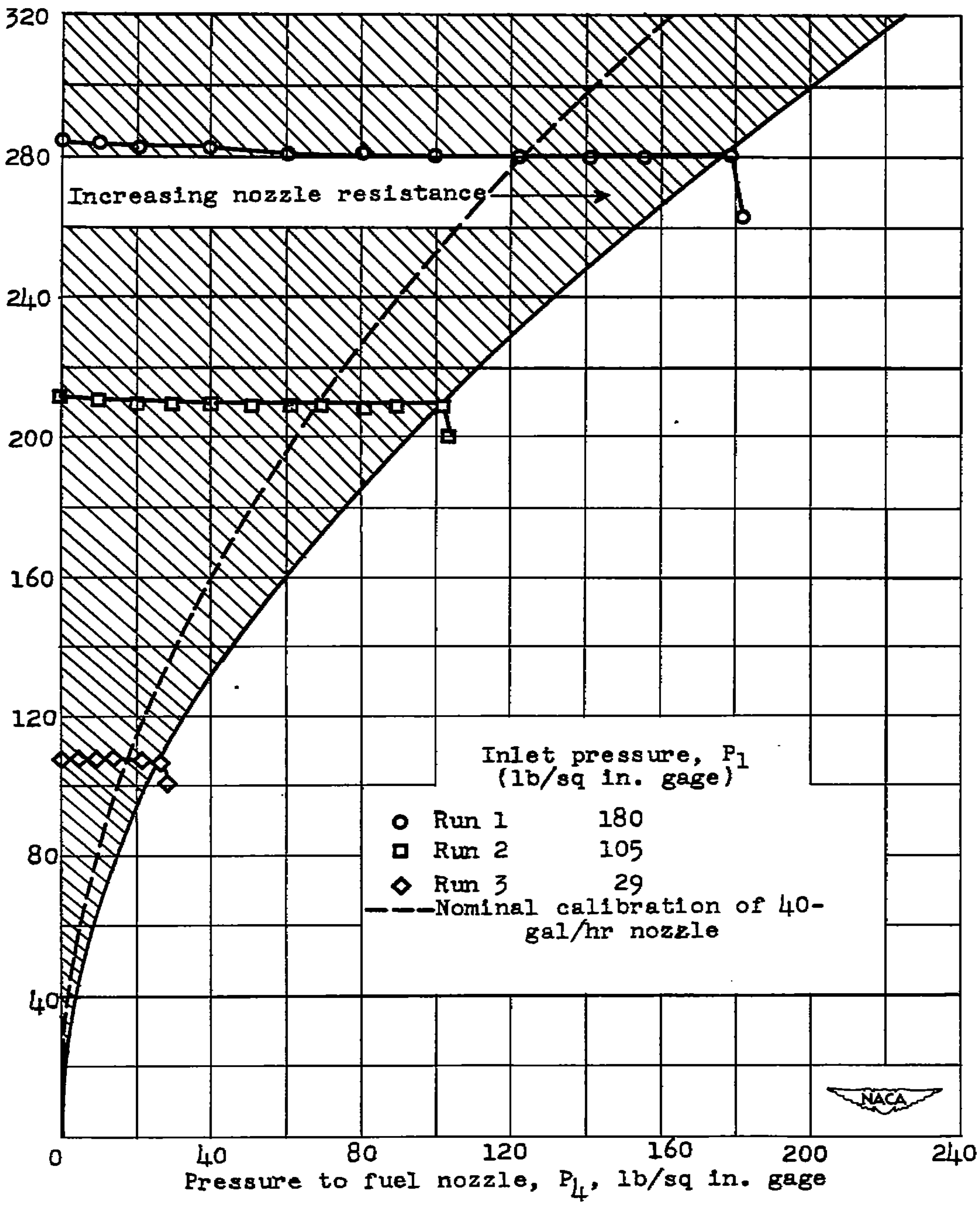


Figure 9. - Compensation for varying resistance of engine fuel nozzle by automatic adjustment of pressure to nozzle. Fuel-distribution control for gas-turbine engine having 14 nozzles, each rated at 40 gallons per hour. Shaded area indicates range of controllable nozzle calibrations.

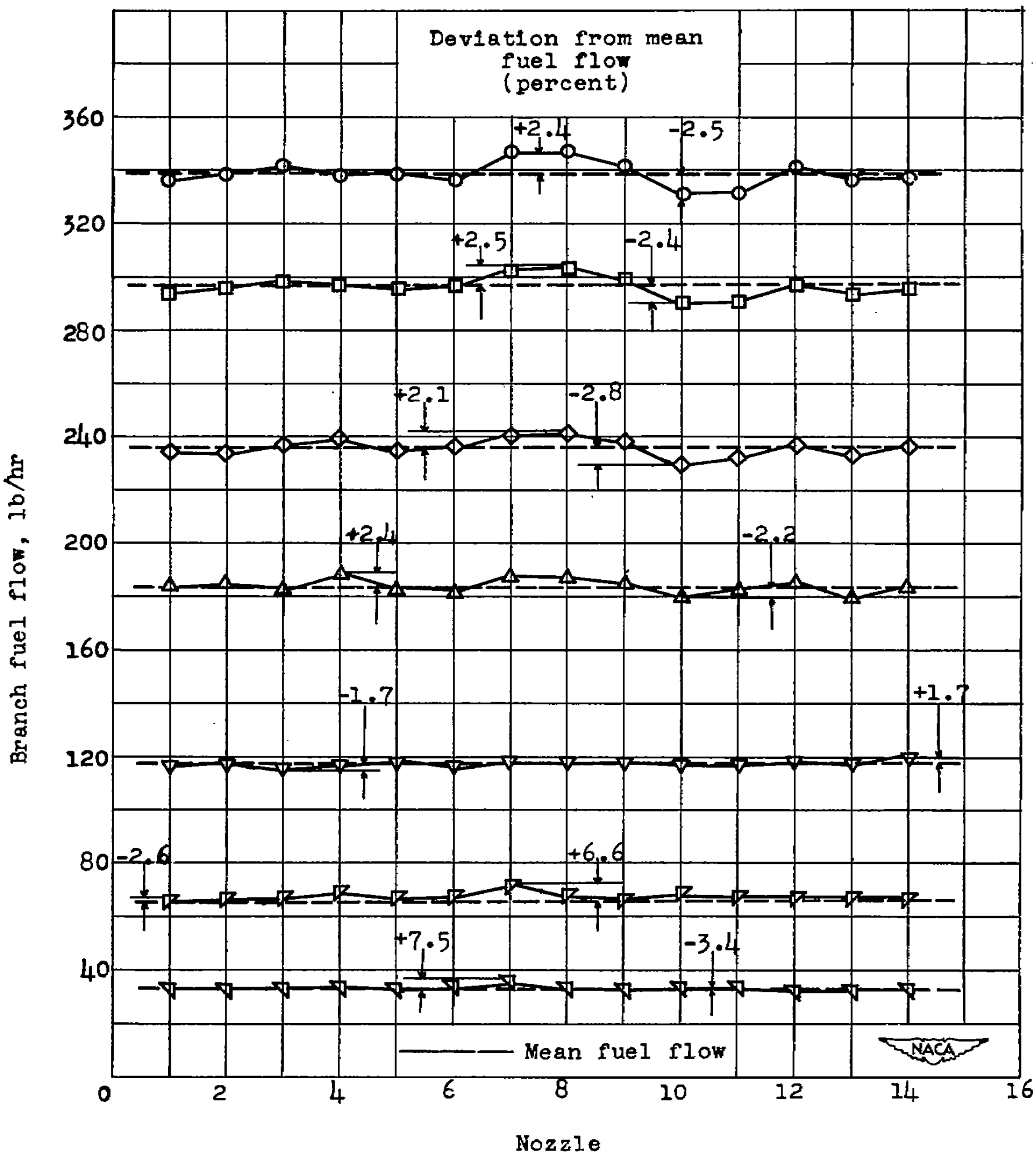


Figure 10. - Deviation from mean fuel flow at various flows during bench runs with unmatched nozzles obtained with fuel-distribution control for gas-turbine engine having 14 nozzles each rated at 40 gallons per hour.

904

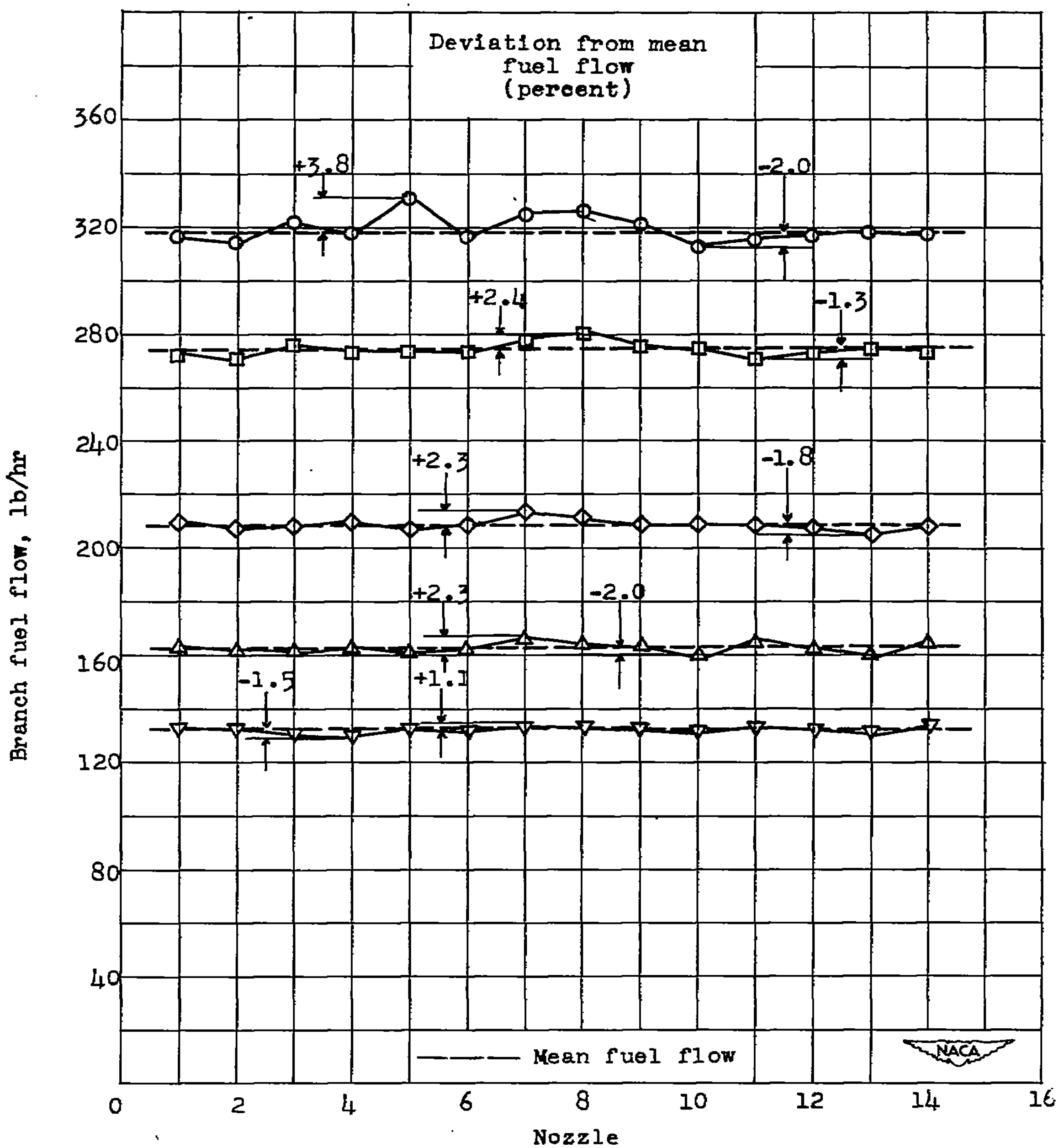


Figure 11. - Deviation from mean fuel flow at various flows during engine runs with fuel-distribution control operating on gas-turbine engine having 14 fuel nozzles each rated at 40 gallons per hour.

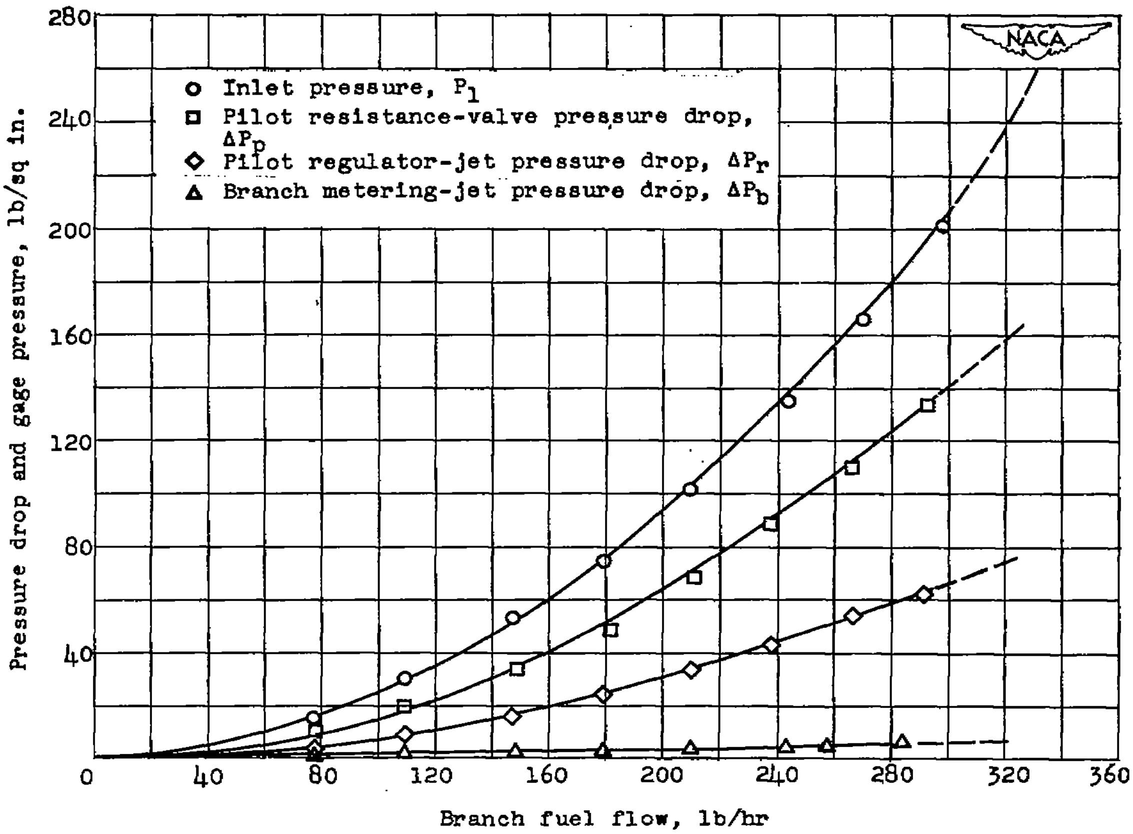


Figure 12. - Pressure drops and pressures in fuel-distribution control for gas-turbine engine having 14 fuel nozzles each rated at 40 gallons per hour.